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Research paper

Integrated Flood Management in developing countries: balancing flood risk, sustainable livelihoods, and ecosystem services

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ABSTRACT
To manage flood risk, floodplains are often designated for uses that support flood storage and ecosystem conservation. In such cases, direct human uses of flood-prone land are often restricted. Despite effectiveness at reducing flood risk, the exclusion of direct human uses from flood-prone lands is not always possible. Additionally, where livelihoods are tied to the use of flood-prone land, such strategies may eliminate floodplain-related benefits. To support implementation of Integrated Flood Management suited to such contexts, we propose a framework in which the livelihood benefits of direct floodplain use are distinguished from those supplied through ecosystem services. Decision-makers may apply this approach where flood risk, ecosystem, and livelihood objectives must be balanced. Because flood adaptation strategies may involve risk-benefit trade-offs, we propose the integrated assessment of flood risk and probabilistic benefits to inform decision-making. Through parallel analysis of probabilistic damages and benefits, a broad suite of management actions may be evaluated to minimize flood risk while maximizing river-derived benefits. Application of the proposed framework and risk-benefit analysis may highlight effective solutions that reflect the pressures and opportunities of developing countries. For instance, measures that reduce flood risk by targeting coping capacity and adaptation, as opposed to flood exposure, may be emphasized.

Keywords: Integrated Flood Management; flood risk; sustainable livelihoods; ecosystem services; flood adaptation; developing countries

1 Introduction

Human use of flood-prone land is often associated with the potential for flood damages and negative societal impacts. Flood management paradigms therefore frequently emphasize relationships between society and flood risks (Schanze 2006). For instance, flood management decision-making is often supported by risk assessment, which in practice often quantifies only the damaging effects of flooding (Meyer *et al.* 2009a, Merz *et al.* 2010b). From a single-objective perspective, reducing human vulnerability by limiting exposure to flood hazards is often an effective strategy to reduce flood risk. Where reduced exposure is accomplished by 'keeping people away from floods', for example, through land-use designations and restricted floodplain uses, river processes driven by hydrologic variability remain intact, promoting river and floodplain integrity. Complimentary ecosystem benefits that follow from establishing natural hydrologic processes within rivers and floodplains create an ideal multi-objective partnership between efforts to manage flood risk and river ecosystems (Opperman *et al.* 2009). As climates become more variable and less predictable, this multi-objective partnership expands to enlist climate change adaptation among the suite of potential benefits (Palmer *et al.* 2009, Seavy *et al.* 2009). The win–win combination of ecosystem approaches for flood-prone land management has been well received and adopted by many flood adaptation and restoration practices in developed countries (Nienhuis and Leuven 2001, Moss 2007).

Another multi-objective approach to flood risk management, the Integrated Flood Management (IFM) concept, promotes maximizing benefits from the use of frequently inundated areas while reducing potential damages from floods (APFM 2004).

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Conceptual ideas of river management by IFM represent a broader and more inclusive approach to managing floods, ecosystems, and sustainable livelihoods, as compared to single-objective flood control strategies (Grabs *et al.* 2007). Many ecosystem approaches for flood-prone land management promote opportunities related to natural hydrologic function, including regular floods, and societal benefits from flood-prone lands (Baron *et al.* 2002). Such ecosystem approaches implemented in developed countries are potentially useful models to support IFM in developing countries. Many example practices, however, often reinforce notions of safety and resource optimization based on the principle of 'keeping people away from floods'. In practice, land-use zoning or designation of flood-prone land for flood risk reduction and nature restoration/conservation often limits the accepted uses of flood-prone land to exclude many direct human values (Dufour and Piégay 2009). However, the exclusion of direct human uses from flood-prone lands is not always possible, or in some cases may not present the most optimal solution. This may be the case for developing and rural areas, or where livelihoods of local people are sustained from direct use of floodplain resources (Cuny 1991). Practices which optimize livelihood benefits of using flood-prone lands in combination with flood risk reduction and ecosystem services may provide unique opportunities and advantages for less-developed nations. Despite the promising future of such multi-objective floodplain management approaches, the lack of practical tools and strategies may hamper their implementation. As trade-offs may exist, it is critical to address the distribution of benefits from direct human use versus exclusive conservation of flood-prone lands in order to achieve equitable outcomes.

In this article, we examine the challenges and opportunities for ecosystem approaches to flood risk management in developing countries and propose a framework for balancing flood risk, sustainable livelihoods, and ecosystem services in flood-prone lands. We further propose that analysis of both risks and benefits associated with floods and use of flood-prone lands may serve as a useful tool to inform selection and implementation of potential flood risk and land management actions. This approach may elucidate appropriate flood-prone land management practices in developing countries and support opportunities for IFM.

2 Integrated Flood Management (IFM) and ecosystem approaches for flood-prone land management

IFM is a philosophy for integrated land and water resources development, aimed to maximize net benefits from the use of flood-prone areas while simultaneously reducing flood losses (APFM 2004). The novelty of this concept is the goal of balancing development needs, environmental quality, and flood risks to support sustainable development (Grabs *et al.* 2007). Principal elements of IFM include managing flood risk and uncertainty, developing an appropriate mix of flood management strategies, and facilitating a participatory process (APFM 2004). One key aspect of IFM is the integration of land and water management. In practice, various ecosystem approaches for managing flood-prone land embody the IFM philosophy (see Table 1). Strategies for adapting flood-prone land uses originate from different disciplines and frameworks such as Restoration Ecology, Flood Management, Integrated River Management, Ecosystem-based Adaptation (EbA) or Eco-based Disaster Risk Reduction (Eco-DRR). Though deriving from varied schools of thought and aimed at diverse objectives, these approaches often share a common strategy of restricting and adapting land uses in flood-prone areas and allowing rivers to temporally flood large areas (Clarke *et al.* 2003, Klijn *et al.* 2004, van Eijk *et al.* 2013). Examples include restoration and/or legal designation of wetlands and floodplains to support natural flood attenuation (Hey and Philippi 1995, Galat *et al.* 1998, Wharton and Gilvear 2007, Ibe *et al.* 2014), or the engineering of flexible embankments that allow adapted, multipurpose use of lands prone to seasonal flooding (Eakin and Appendini 2008, Edelenbos *et al.* 2013).

Interventions that include restoration of rivers, flows, and floodplains derive from geomorphic and ecological principles, and often seek to re-establish hydrological, ecological, and geomorphologic processes of rivers (Sear 1994, Poff *et al.* 1997, Ward *et al.* 2001). These practices are often based on recovering ecological integrity through the reconnection of rivers with floodplains (Buijse *et al.* 2002, Jungwirth *et al.* 2002). In practice, use of restored floodplains is often restricted to the few categories of land use which are robust to periodic inundation, such as conservation, green space, and limited seasonal agriculture or pasture (Bernhardt *et al.* 2005, Purps *et al.* 2005, Wohl *et al.* 2005, Moss 2007). As the reference state for most restoration projects is a natural and uncompromised river–floodplain system with limited human disturbance, designed uses of reconnected floodplains often exclude cultural and socio-economic values (Buijse *et al.* 2005) such as residential or commercial uses.

'Space for the River' or 'Room for the River' practices largely originate from a flood management domain (van Stokkom *et al.* 2005, Hartmann 2013, Potter 2013). These practices consist of floodplain restoration to increase retention capacity of rivers (Warner *et al.* 2013). Similar to river restoration projects, 'Room for the River' projects also promote ecological integrity and natural dynamic processes within designated river–floodplain areas (Hooijer *et al.* 2004, Warner and van Buuren 2011, Potter 2013). For example, interventions such as levee setbacks, ring polders, or river side channels (Nijland 2005) delineate zones within which natural flow patterns and processes are allowed. In some cases 'Room for the River' projects such as in the Noordwaard and Overdiepse Polders, the Netherlands, include a compatible multifunctional use of flood-prone areas in which residences and agricultural activities are protected with the strategic location of polders or by placing homes and farm buildings on raised platforms (Edelenbos *et al.* 2013). In other areas, the multifunctional approach of 'Room for the River' projects lists cultural use, preservation of heritage, and

Table 1 Ecosystem approaches for flood-prone land management to support IFM

Approach	Definition
Integrated River Management	• Aims for the sustainable development and long-term stability of various elements of river systems, such as morphology, ecology, landscape, and human use (Wang *et al.* 2015). • Practices may include restoration of lateral and vertical connectivity of rivers, with appropriate integration and coordination of different interests, domains, and functions (Verkerk and van Buuren 2013, Wang *et al.* 2015).
EbA	• Considers integration of conservation, restoration, and sustainable use of biodiversity and ecosystem services for human well-being and adaptation to climate change (Millennium Ecosystem Assessment 2005, Secretariat of the Convention on Biological Diversity 2009). • Main goal is to increase resilience and reduce vulnerability of people to climate change, promoting the use of traditional knowledge and local practices (Colls *et al.* 2009).
Eco-DRR	• Defined as the sustainable management, conservation, and restoration of ecosystems to reduce disaster risks and achieve resilient development (Estrella and Saalismaa 2013). • Highlights the interrelation between ecosystem management, disaster risk management, and climate change adaptation (Sudmeier-Rieux and Ash 2009). • Emphasizes the role of ecosystems for natural protection against hazards and for sustaining livelihood resilience (Estrella and Saalismaa 2013).
River restoration	• Defined as recovering the ecological integrity in a degraded watershed system by re-establishing the processes necessary to support the natural ecosystem within the watershed (Wohl *et al.* 2005). • Aims to recover spatial river processes, for instance, the natural sinuosity of channelized rivers, lateral connection of rivers with their floodplains, longitudinal connectivity along the stream, and the vertical connections between river channels and underlying hyporheic zone (Kondolf *et al.* 2006). • Recovery of temporal river processes is mainly addressed through restoration of natural flow regimes and dam decommissioning (Richter and Thomas 2007).
Space or Room for the River	• Aims to create more space for rivers usually by increasing the river channel capacity or adapting floodplains to sustain flooding (Warner *et al.* 2013). • Measures are driven by flood safety and restoration objectives, but often enlist climate change adaptation (Verkerk and van Buuren 2013). • Example practices mostly derive from application of comprehensive policies, multi-stakeholder involvement, and sometimes include multiple benefits from flood-prone areas (Wiering and Arts 2006). • Different characteristics between practices seem to be evident with regard to the type of measure, scale of intervention, sector outreach, and the benefits often associated with the promotion of flood-adapted areas (Verkerk and van Buuren 2013).

improved navigation as co-benefits (Corvers 2009, Zevenbergen *et al.* 2013). Often 'Room for the River' measures are linked with transitions in policies, governance, planning, and decision-making (Wiering and Arts 2006, Rijke *et al.* 2012). For instance, Dutch water managers have adjusted their traditional roles to facilitate nature development and multidisciplinary cooperation in 'Room for the River' projects (Roth and Warner 2007, Klijn *et al.* 2013).

Efforts that unfold from Integrated River Management, EbA, and Eco-DRR approaches account for interactions between natural and human systems (Nakamura 2003, Renaud *et al.* 2013, Wang *et al.* 2015). The main attribute connecting these approaches is the combination of multiple objectives, such as flood safety and sustainable use of land and water resources (Maltby and Blackwell 2005). Projects may consider not only ecological quality of river systems or flood safety, but also acknowledge the potential use of floodplains and local adaptation capacities (van Eijk *et al.* 2013, Verkerk and van Buuren 2013, Wang *et al.* 2015). In EbA and Eco-DRR projects, socio-economic and livelihood aspects are assumed to derive from the ecosystem services provided by functioning river–floodplain systems. Direct socio-economic benefits related to direct human use of flood-prone land may not feature prominently in projects implemented under such frameworks.

Considering the diversity of ecosystem approaches for flood-prone land management, these approaches may lead to a spectrum of possible flood-prone land conditions. Potential configurations may involve exclusive nature conservation of flood-prone lands, to multifunctional floodable areas where direct human uses are acceptable. Depending on the local and river basin contexts, these example practices therefore have great potential to serve as flood-prone land management models, which may be useful in supporting implementation of IFM.

3 Benefits from direct human use and exclusive conservation of flood-prone land

The varied land management models from joint flood risk-ecosystem approaches can produce a diverse array of potential benefits with respect to rivers and floodplains (Thorp *et al.*

2010). We distinguish benefits associated with direct human uses of floodplains from societal benefits that derive from designating floodplains exclusively for ecosystem conservation (Figure 1). For instance, a river restoration project may entail reoperation of a flood control dam to restore naturally occurring floods, in combination with floodplain zoning and acquisition of flood-prone land for conservation purposes. The restoration of hydrologic processes and repurposing of flood-prone land to accommodate regular flooding produces benefits in both flood risk management and improved river ecosystem function. Although many direct human uses of the flood hazard area are prohibited in this case, the designation of floodplains for conservation provides ecological and societal benefits through provision of ecosystem services. In accordance with Hein *et al.* (2006), some of these benefits in practice may involve an 'indirect use' and 'non-use' value, such as maintenance of channel morphology and natural habitats, flood regulation, and clean water or a 'direct use' value such as navigation or recreation (Holmes *et al.* 2004, Bernhardt *et al.* 2005, Wohl *et al.* 2005, Verkerk and van Buuren 2013). This exclusive conservation model is in contrast to management models that allow humans to directly attain tangible benefits from direct use of floodplains, for instance, from agriculture, pasture, and housing.

In developed countries, ecosystem approaches to floodplain management often support benefits and services related to 'regulation', 'habitat', and 'information (cultural)' functions of riverine systems (Figure 1). As floodplains are often designated exclusively for conservation and flood storage uses, these approaches often exclude many direct human uses of the land. Direct human use of flood-prone land is frequently associated with loss of lives and/or economic value, as people and assets are exposed to flooding. In consequence, while the definition of IFM acknowledges the benefits associated with human use of flood-prone land, many approaches in practice tend to eliminate direct human use of floodplains in favour of benefits compatible to conservation and flood storage. The strategy of 'keeping people away from floods' may therefore become implicit in measures aimed for risk reduction and ecosystem benefits. This may discount the full continuum of possible benefits from flood-prone areas. Where the exclusion of humans from floodplains is unrealistic, the lack of alternative models illustrating how direct human uses may be undertaken within the context of ecosystem approaches to flood risk management, may impede implementation of ecosystem approaches.

4 Flood-prone land management in developing countries

Trends in altered and degraded river systems and potential impacts of climate change (Tockner and Stanford 2002, Mirza 2003) may drive implementation of joint flood risk-ecosystem approaches in developing countries. The exclusion of direct human use of floodplains, however, may be a poor fit in the developing world. Rapid population growth and corresponding land pressure (Tockner *et al.* 2008) may challenge practices based on 'keeping people away from floods' as people expand into marginal land such as floodplains. In Bangladesh, for example, increasing population density and high rates of rural–urban migration force landless families to settle in available lands, which are often disaster-prone areas alongside or within major rivers (Wisner *et al.* 2004, Webster *et al.* 2010). Even when human uses of flood-prone land are legally excluded, responsible institutions in many developing countries often fail to enforce these laws. For instance, China's flood management strategy designates a total of 98 flood retention zones for flood water storage (Cheng 2005). However, after years of encroachment and intensification of human activities, almost 2 million hectares are still used for agriculture and more than 17 million people live within these zones (Han and Kasperson 2011). People in developing countries may refuse to reallocate or settle back into flood-prone areas, partly due to weak governance, but also because many people living in such lands often must balance flood risk with other types of risk and social needs (Weng Chan 1995). For instance, poor people may be exposed to flood risks but, if excluded from the resources of flood-prone land, may face even greater livelihood risks

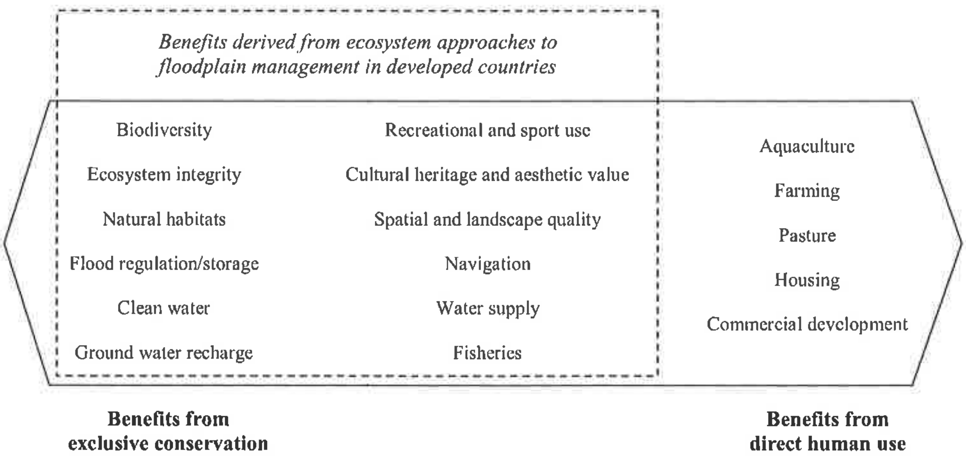


Figure 1 Continuum of potential benefits from flood-prone areas.

(Arnall *et al.* 2013). People may, for example, have limited or no access to resources, monetary income, or water for domestic use and sanitation. The goods and services they might obtain from floods and use of flood-prone lands therefore represent their means of survival, making life in a hazardous area the best of poor choices. Evaluation of resettlement schemes for reducing flood risk in Malaysia reveals that important challenges to reallocation are uncertainties of moving to new environments and strong values and attitudes to current ways of living in the communities (Weng Chan 1995). Evidence from two villages in Mozambique also highlights the ability to secure a viable livelihood as a key determinant explaining whether resettled peoples remain in their new location or settle back in the floodplains (Arnall *et al.* 2013). In developing countries, policy-makers and managers may also prioritize development goals above conservation. For instance, a manager may veto joint conservation-flood risk schemes that limit human economic activities in favour of projects that enable economic growth following the Western model of development. In the Philippines, for example, strategies in favour of aquaculture development, perceived low economic rent of mangroves, and lack of political will are listed among institutional factors that have compromised the sustainable development and conservation of mangrove ecosystems in the country (Primavera 2000).

In many countries, and particularly in delta nations such as Vietnam and Bangladesh, floods occur annually and direct exposure to seasonal flooding is expected and anticipated by local people. Many people derive direct benefits from 'living with – and from floods' (Cuny 1991). Natural floods and floodplains have long provided multiple goods and services to communities, for instance, supplying soil moisture, nourishing fields with nutrients and sediment, and bringing fish into floodplain-rearing habitat (Paul 1997). In many respects, floods are considered beneficial for agriculture and fisheries activities (Shankar *et al.* 2004). Housing is often adjusted to withstand some level of inundation (Cuny 1991), allowing people to live close to or on flood-prone land. Many people have therefore developed livelihoods and lifestyles which are tied to seasonal flood pulses (Paul and Routray 2010). In Vietnam, for example, 'living with floods' includes seasonal planting of crops to avoid flood peaks or elevating paddy fields and building small-scale bordering embankments to protect crops (Tinh and Hang 2003). Common practices also include evacuation to high grounds during flood season and constructing elevated homes (Few *et al.* 2004). In such contexts, people able to cope with certain levels of inundation obtain direct socio-economic benefits of using flood-prone land.

Resources deriving from floodplains provide a considerable fraction of annual incomes and assets, and in some areas floods are important natural processes that support the base of rural economies and food security (Few 2003). For people living in these conditions 'normal' floods are therefore not considered a disaster, but both the lack of flooding and extreme flood events are associated with negative consequences (Tinh and Hang 2003). Strategies that include relocation of people and designation of flood-prone land for conservation and flood risk reduction are therefore not necessarily desirable or feasible in many developing countries. However, flood-prone land management models may contribute to maintain healthy ecosystems, while providing opportunities to sustain flood-adapted livelihoods and reducing potential flood risks. Hence, these practices may be useful in supporting and achieving main goals of IFM in developing countries. The interpretation of benefits in these contexts must, however, value benefits from both conservation and direct human use of flood-prone land. This notion may suggest that flood-prone land adaptation and restoration efforts must include configurations that balance livelihoods, ecosystem services, and benefits while reducing hazard risks. The process towards implementation of adequate practices should therefore build from lining-up and rightly acknowledging these elements and their interactions.

5 Balancing risks, livelihoods and ecosystem services in flood-prone lands

To support implementation of ecosystem-based approaches to managing flood-prone land in developing countries, there is a need for models and example practices that are suited to the context of developing nations or where human exclusion from floodplains is not possible. Such approaches require recognition of the opportunities and benefits that derive from direct use of flood-prone lands. We propose that livelihood benefits deriving from direct use of flood-prone land should be distinguished from those supplied through river- and floodplain-related ecosystem services. In order to evaluate the full scope of potential benefits, we propose a framework that emphasizes livelihood and socio-economic benefits, both from direct use of flood-prone land, as well as those related to ecosystem services derived from the preservation of natural hydrologic processes (Figure 2). Balanced consideration of ecosystem services and direct livelihood benefits may illuminate a wider range of adaptations and land-use options that maximize the benefits of using flood-prone land, while promoting connection of rivers and floodplains and minimizing flood risk. In this way, alternatives to established models of exclusive ecosystem-flood storage uses are imaginable, encompassing strategies and adaptations that support many other potentially beneficial human uses of flood-prone lands. This framework may be used to explore and select management practices when a strong basis for securing livelihoods and favourable river environments is desired, for instance, through the optimization of both flood risks and benefits.

5.1 *Targeting coping capacity to mitigate risk*

Our proposed framework balances livelihoods, ecosystem services, and risk management. Translating this approach into practice, however, may require targeting risk from a broad

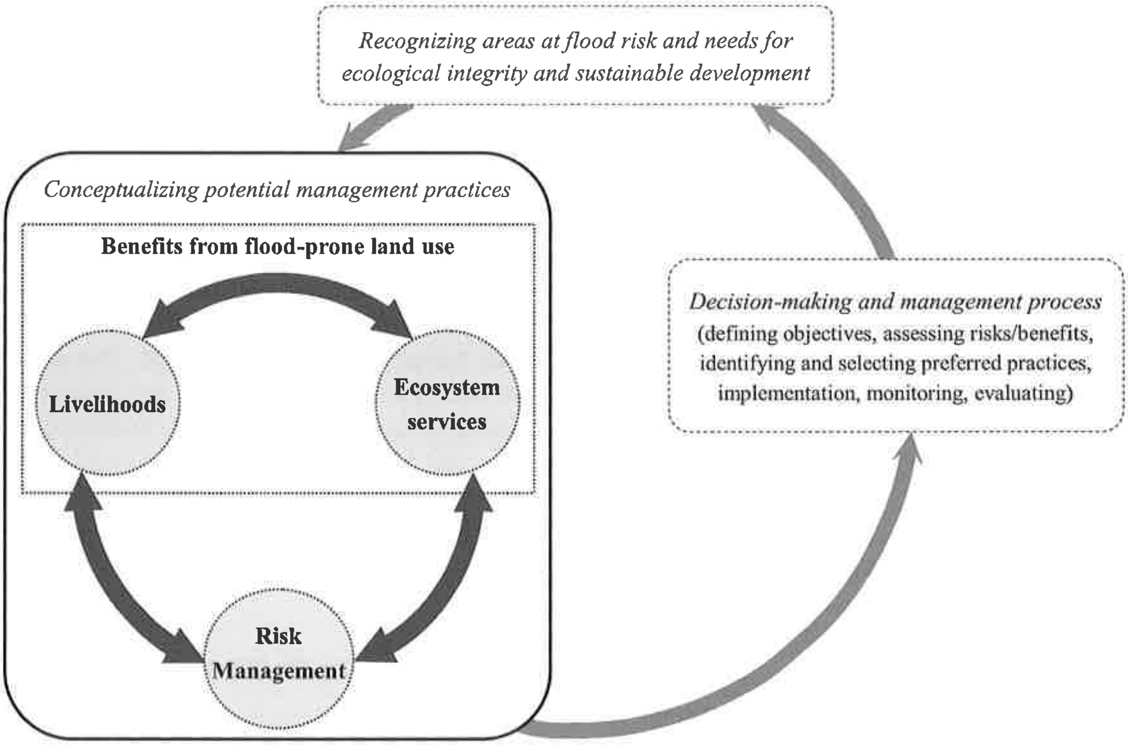


Figure 2 Conceptual framework for balancing flood risk, livelihoods, and ecosystem services in flood-prone lands.

perspective. Risk in flood management is defined as the probability that flood hazard will combine with vulnerability to produce negative consequences (Merz *et al.* 2010a). Vulnerability is often expressed as a function of Exposure and Coping Capacity; thus, risk may be expressed as in Eq. 1.

$$\text{Risk} = f(\text{Hazard, Exposure, Vulnerability, Coping Capacity}). \quad (1)$$

If, for example, there is no exposure to a hazard then the possible range of probabilistic hazards pose minimum or no risk. Similarly, if vulnerability is reduced (for instance, through enhanced coping capacity), exposure to hazards may lead to fewer negative consequences, which also reduces risk. Many models for managing flood-prone land in developed countries tend to limit hazard exposure as a mechanism to reduce flood risk. The potential to minimize flood risk by targeting and enabling coping capacities is frequently overlooked in favour of strategies that 'keep floods away from people' or 'keep people away from floods'. However, by targeting coping capacities rather than exposure as a strategy for risk reduction, it may be possible to simultaneously support flood risk reduction, livelihoods, and ecosystem services. Measures aimed to secure livelihoods while supporting other ecosystem services from natural river functions, most likely will involve land-use scenarios under some level of exposure to flood hazard. Increasing coping capacities and supporting traditional knowledge are perhaps the keys to delivering multiple benefits from using flood-prone lands while minimizing flood risk (Figure 3).

Supporting ecosystem services such as natural flood processes while simultaneously securing livelihoods, for instance, through agricultural and fishery activities, may involve a scenario in which people are exposed to regular flooding. Enhancing coping capacities, for example, through seasonal adaptation of livelihoods such as alternating crops during the dry season with fishing during the wet season, may be an effective way to minimize potential losses and thus manage flood risk. Alternately, a scenario in which flood storage or natural flow regime services are promoted while allowing economic activities and residential use of flood-prone lands, may be an acceptable option if local capacities to save properties and assets are supported by early warning systems, flood risk maps, and risk education.

5.2 *Supporting livelihoods, ecosystem services, and other benefits*

Depending on the approach behind floodplain use, trade-offs in resultant benefits may occur, such that certain values are favoured relative to others. For instance, it is often assumed that benefits of restoration may be realized only when human disturbance is minimal or inexistent. Similarly, that human development can only be achieved if the environment is fully adapted and modified to fulfill societal needs. In other words, conservation and development goals are conflicting and therefore benefits to one sector may only accrue under conditions that limit provisioning of benefits to the other. In reference to floodplains, this assumption may apply in some cases, as projects promoting multifunctional use of floodplains still involve complex engineering works or alteration of natural processes. In the prior example of

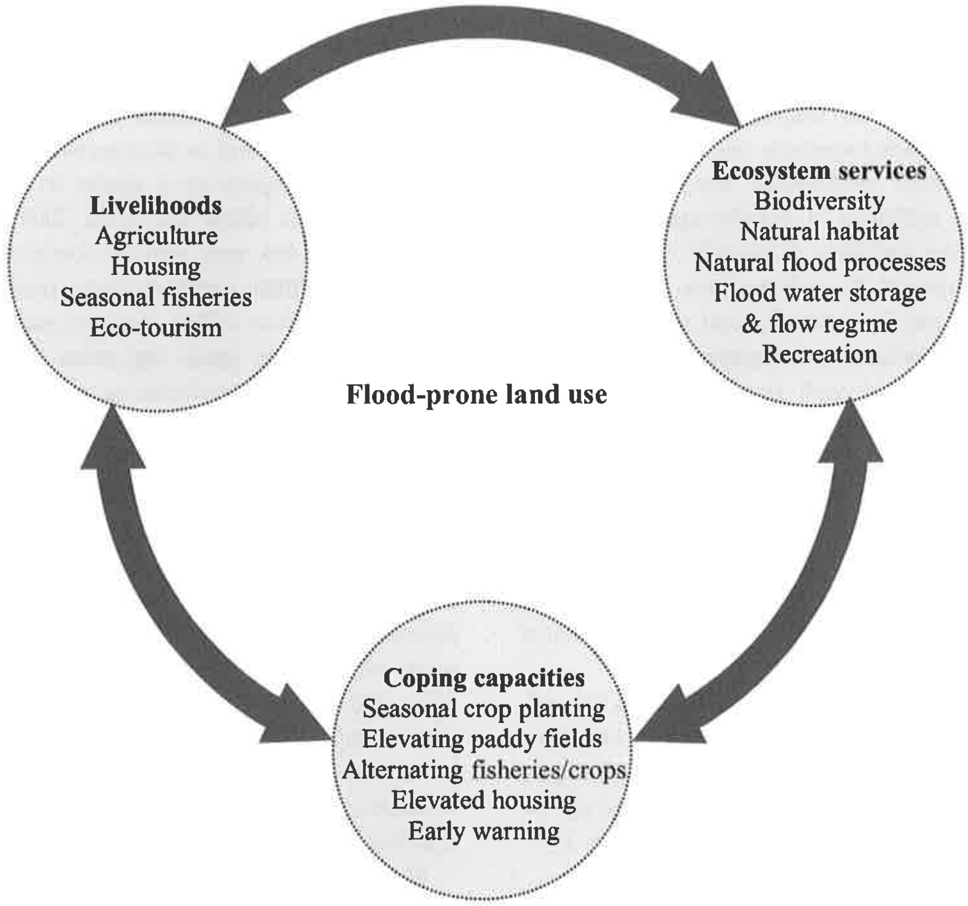


Figure 3 Enabling coping capacities to sustain livelihoods and ecosystem services and benefits in flood-prone lands.

'Room for the River' in the Noordwaard Polder, agricultural areas are converted into a multifunctional space with different flooding frequencies to restore flood and tidal dynamics and support nature development (Edelenbos *et al.* 2013). The final design includes the strategic location of high-diked polders to protect living and agricultural activities; however, the long-term effects on the delta Rhine features remain uncertain as sedimentation processes were largely overlooked (van Staveren *et al.* 2014).

Though inevitable trade-offs can result from securing livelihoods as well as supporting ecological integrity of river systems, these elements are not necessarily mutually exclusive. For instance, establishing or maintaining a natural regulation cycle in flood-prone lands may provide different types of ecosystem services and goods (i.e. ecological, socio-cultural, and economic). Livelihoods which are also tied to or dependent upon natural hydrologic regimes can be enhanced in a similar way. For instance, in the case of developing countries, this may apply for agriculture and fisheries-based livelihoods, and local tourism industries may also benefit from sustained natural environments. The key to crafting projects that provide benefits to multiple sectors (economic, ecosystem, flood risk reduction) may lie in articulating very clearly where risk and benefits occur in order to design strategies that derive the maximum benefit for the minimum risk.

6 Flood Risk-Benefit Assessment: delivering information for flood-prone land management

Risk assessment is an important tool to inform decision-making and support implementation of flood management practices. Conceptualization of risk in flood management largely aligns with the scientific definition of risk, such that risk is often objectively quantified as the product of probability and consequence. The purpose of flood risk assessment is to determine potential consequences related to various magnitudes of flood hazard, such that measures to reduce damages and loss are designed, evaluated, and selected according to the probability of occurrence. Current application of risk assessment mostly focuses on damages with respect to assets and lives (Merz *et al.* 2010b). Other societal and environmental consequences are frequently neglected, sometimes resulting in the selection of countermeasures that manage only certain elements of flood risk (Meyer *et al.* 2009a). Despite wide acknowledgement of potential benefits that derive from direct use of flood-prone lands, techniques in flood risk assessments that explicitly include benefits are still limited (Meyer *et al.* 2013). Rather, risk assessments generally consider benefits in terms of loss avoidance of possible measures (Messner and Meyer 2006).

We posit that coupled assessment of flood risks and probabilistic benefits can be an improved information tool to support balancing livelihoods, ecosystem services, and flood risk management. For instance, if benefits from floods and use of flood-prone lands are properly integrated and evaluated next to risks of flooding, decisions to alter the magnitude of designed peak flows will be targeted to simultaneously reduce risk and align with local socio-economic preferences and environmental goals. In addition, the exchange of benefits against tolerable risks may reveal a wider spectrum of possible scenarios. For example, a naturally-restored floodplain where human use is limited may provide ecosystem benefits and very low flood risk; alternatively, a multifunctional floodplain may support similar ecosystem services as well as benefits from direct human use in exchange for tolerable levels of flood risk. The evaluation of acceptable risk and benefit trade-offs in decision-making can function as criteria for balancing various benefits while minimizing potential loss to support IFM. Targeted at the correct scale, the broader context provided by a Flood Risk-Benefit Assessment may represent local conditions and desired objectives, which may ultimately support more effective and socially compatible solutions.

We propose a step-wise approach to integrate benefits into risk assessments (Figure 4(a)–(e)). Flood risk is assessed by combining a probability density function of flood hazard ($f(x)$; Figure 4(a)), with a damage function ($D(x)$; Figure 4(b)) to obtain a probabilistic damage function (Figure 4(c)) as described in Eq. 2:

$$\mathrm{RI} = \int_0^\infty f(x) \cdot D(x)dx, \qquad (2)$$

where $f(x)$ is the probability density function of flood magnitudes x, and $D(x)$ is the relation between damages D and flood magnitudes x. The integration of $f(x)$ and $D(x)$ for possible range of x results in the expected damage (RI). An analogous process may be applied to assess benefits, which may therefore include generation of functions $B(x)$ that relate benefits with flood magnitudes (Figure 4(d)) to estimate the expected benefit (BE) from floods as indicated in Eq. 3 (Figure 4(e)):

$$\mathrm{BE} = \int_0^\infty f(x) \cdot B(x)dx. \qquad (3)$$

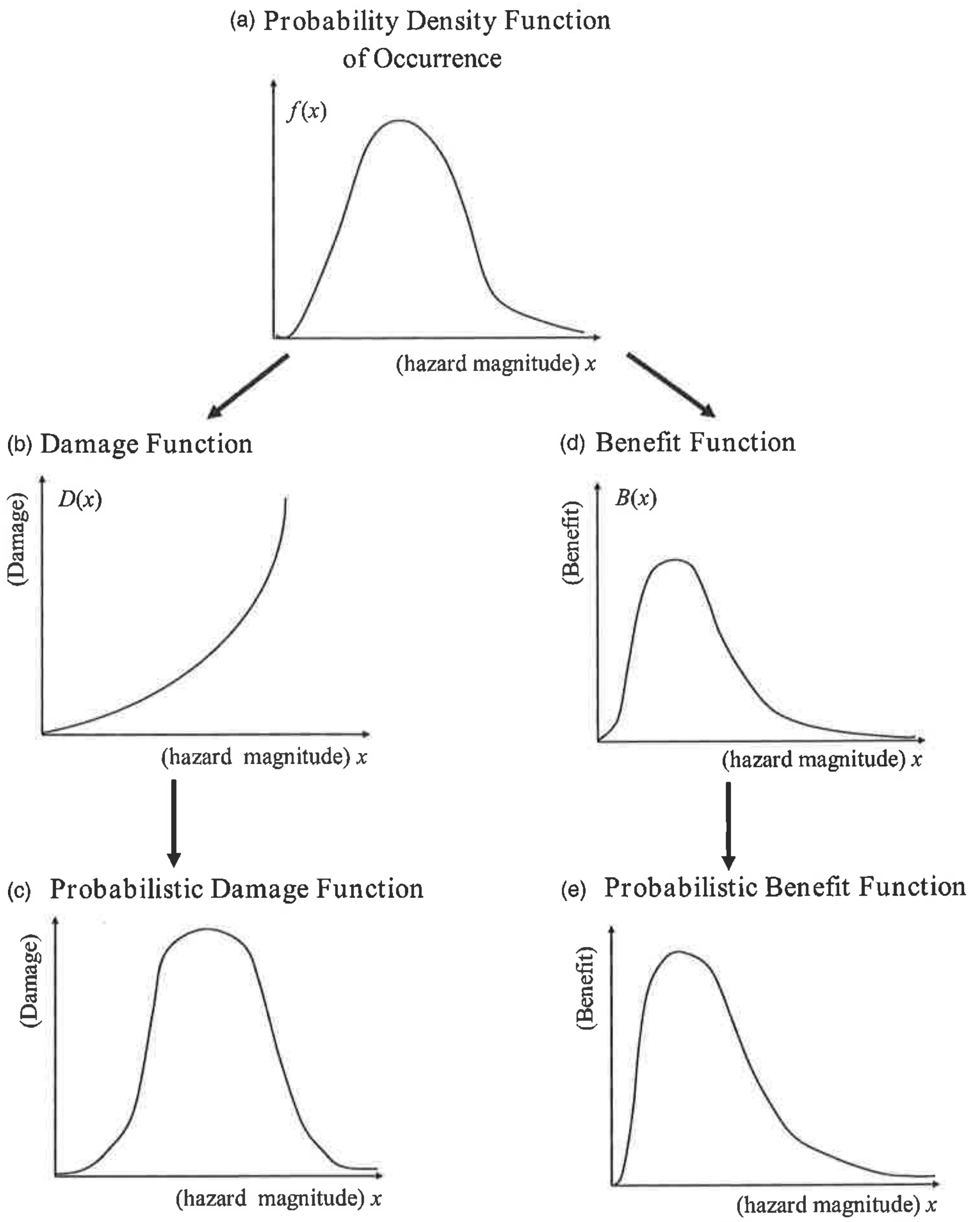
When balancing probabilistic damage and benefit functions in a common profile, the range of return periods associated with potential benefits and risks as well as maximum turning points, may be useful in supporting understanding and consensus among stakeholders. Such information can facilitate improved decision-making and ultimately the development of socially acceptable floodplain management.

7 Challenges and opportunities of Flood Risk-Benefit Assessment

Although Flood Risk-Benefit Assessments may be a promising concept, it is worth recognizing potential challenges and limitations to application. As mentioned previously, risk in flood management is most often objectively quantified as the combination of hazard probability and resulting consequence. As such evidence is often used to support analyses of cost-effectiveness, risk as an objective measure appeals to governments and experts as a means to evaluate and compare countermeasures (Baan and Klijn 2004). It is worth noting, however, that risk may also be conceived as a collection of perceptions which influence how people perceive hazards (Raaijmakers *et al.* 2008). Aspects such as perceived preferences or possible gains are often decisive when humans judge hazards and determine acceptable levels of risk (Baan and Klijn 2004). Past experiences and emotion may also be influential to risk perception (Slovic *et al.* 2004, Raaijmakers *et al.* 2008). Additionally, risk of a given hazard is rarely contemplated in a vacuum. Humans perceive and understand risk largely as a relative function, such that acceptable risk of flood is perhaps determined relative to risk of other hazards. Perceptions and views on risk can thus differ between government, managers, experts, and community members (Baan and Klijn 2004) or vary at the individual and community level and amongst cultures. Risk assessment approaches focused on statistical risk alone can therefore lead to sub-optimal decision-making if perceived or acceptable risk is significantly different from managers' assumption.

Both benefits and risks are related to hydrologic conditions that vary through time. This notion brings forward two different aspects of floods: the mid- to high-frequency events that secure many socio-economic benefits and perhaps low levels of damages, and low-frequency flood events that immediately result in catastrophic damages but eventually may provide lagged benefits such as soil fertilization. Risk-Benefit Assessments must therefore expand from current practices in flood management that focus on extreme events, to include low and high flows, seasonality, and perhaps various descriptors of flooding. Moreover, Risk-Benefit Assessments may involve exploring ways to relate potential benefits and damages to probabilistic flooding events. A combination of available methods to characterize flood hazard and value damages (Merz *et al.* 2010b, Meyer *et al.* 2013) and ecosystem services (Hein *et al.* 2006) may help overcome information gaps, but they require careful selection to accurately represent the context at stake.

Risk-benefit profiles may vary depending on the scale of analysis. As risk assessment may not necessarily preclude social disparity, attention to scale is necessary to ensure that benefits and risks are distributed equitably among sectors and communities. For example, if assessments are implemented at a provincial level, risks and benefits relevant to specific communities may not be reflected in identified risk-benefit priorities. Specific preferences may only become evident when assessments are performed at local scales. For example, the use of flood-prone areas for fisheries activities may be valued by specific groups at the community level, but at municipal or provincial levels such benefits may be perceived as marginal. It is



$$\mathrm{RI} = \int_0^\infty f(x) \cdot D(x)dx \qquad \mathrm{BE} = \int_0^\infty f(x) \cdot B(x)dx$$

Figure 4 A step-wise conceptual approach to Flood Risk-Benefit Assessment.

therefore imperative that practitioners target the appropriate scale of analysis for a given objective, to ensure that the 'preferred' risk-benefit profile accurately reflects stakeholder preferences. To capture more realistically desired and just outcomes, potential risks and benefits may be identified with a strong basis on local conditions and preferences, then nested within objectives at broader scales (e.g. river basin, regional scales). Properly acknowledging that risks and benefits may trade off at different scales will allow managers to ensure that 'preferred' risk-benefit levels are effective at all levels.

Flood Risk-Benefit Assessments should include multiple stakeholders' views and require interdisciplinary analysis. Integrating variable stakeholder preferences and finding a common currency for comparing benefits and risks can be challenging. The value perceived from certain benefits, such as biodiversity or wildlife habitat, is often an intrinsic interest and in many cases difficult to measure and capture in units that are comparable (de Groot *et al.* 2002) with flood damages. Traditional flood risk assessment also contends with this challenge in jointly assessing costs of property damage and human lives. When varied stakeholders' opinions are considered in multi-objective decision-making where disparate pieces of information must be integrated, methods such as Multi-Criteria Analysis may be applied (Meyer *et al.* 2009b). Participatory approaches that support social learning processes can be effective mechanisms for achieving consensus and dealing constructively with trans-disciplinary domains and framing of issues (Pahl-Wostl *et al.* 2008). Such approaches might be useful when identifying 'preferred' risk-benefits, as well as when defining units or weights for evaluation and decision-making. For instance, stakeholders may determine threshold values and weights to standardize multiple criteria in a comparable scale (Kiker *et al.* 2005). It is important to acknowledge, however, that such methods introduce subjectivity and depend on the positions, interests, and necessities of the actors involved (Hein *et al.* 2006). With the caveats of firm grounding in justice, appropriate scale of analysis, and adequate stakeholder representation, the integrated assessment of benefits and risks may be a valuable method to support participatory processes and more equitably address some of the complexities behind evaluation and selection of floodplain management practices.

8 Conclusion

Joint flood risk-ecosystem approaches for managing flood-prone land can lead to a spectrum of possible floodplain conditions and uses. However, many flood-prone land adaptations, such as 'River restoration' and 'Space for the River', often emphasize recovering ecosystem integrity and reducing flood exposure to manage flood risk. In line with these principles, the ultimate design of example practices frequently consists of natural river–floodplain systems where human activity is limited. We find that such configurations favour societal benefits which are compatible with conservation and flood storage, such as maintenance of natural habitats, clean water, flood regulation, aesthetic value, and recreational use. In contrast, benefits from direct use of flood-prone lands, for instance, for agriculture, pasture, or housing, are frequently discounted.

In many developing countries 'living with – and from floods' is the de facto management system, where people often base livelihood strategies on hydrologic cycles and direct use of flood-prone lands. Direct transfer of practices from developed countries that limit uses of flood-prone lands or constrict access to flood-adapted livelihoods may be unlikely to succeed in such contexts. Population pressures and poor governance systems that often characterize developing countries may also challenge the adequacy and effective compliance of such practices. Where exclusion of humans from floodplains is unrealistic, our proposed framework for balancing flood risk, ecosystems, and livelihoods can elucidate innovative management practices that allow benefit capture from a wide breadth of potential floodplain benefits. Distinguishing livelihood benefits of direct floodplain use from those that derive from flood- and floodplain-related ecosystem services may stimulate the exploration of floodplain conditions that support the full scope of livelihood and ecosystem benefits.

People living on and using flood-prone lands may be exposed to hazards; thus, enhancing coping capacities (e.g. through early warning or seasonal fish-crop systems) must figure prominently into strategies for managing risk. In evaluating alternative measures following this approach, selection of preferred benefits may involve trade-offs within the range of potential benefits. Managers and decision-makers may also have to consider combinations of tolerable risk levels alongside benefits obtained in exchange. Flood Risk-Benefits Assessments can reveal information about return periods, flood magnitude range, and turning points associated with levels of benefits and risks. This information has the potential to assist evaluation of floodplain conditions bearing different risk-benefit exchanges, which can lead to integrated socio-ecological solutions for implementing IFM. The appropriate integration of justice principles and consideration of scale and spatio-temporal variability may help overcome potential challenges to implementation.

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